GEOTHERMAL RESOURCES IN EGYPT, EXPLORATION AND DEVELOPMENT

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ABSTRACT

Hot springs and active volcanic zones produce geothermal fluids that can be used to generate non-electric energy. This source of energy is a clean and renewable source. Review of hydrological, Hydrogeological hydrochemical and isotopic characteristics for selected geothermal springs and wells in western desert as well as in the Gulf of Suez area has revealed that average water temperature ranges between 35.8 ^{o}C and 41.9 ^{o}C for geothermal water in western desert whereas the geothermal resources of Ayun Musa and Hammam Faraoun show as high temperature as 75 ^{o}C..Total dissolved solids(TDS) of the geothermal springs and piezometers in western desert ranges between 103 ppm and 500ppm while the content of H_2S ranges between 0.09 and 3.5 ppm. Whereas, TDS for Hammam Faraoun and Ayun Musa in Sinai ranges between 2250 and 11440 ppm respectively.The water types of geothermal water in western desert are of NaHCO3 and MgCl types, while that of Hammam Fraoun and Ayun Musa are of MgCl2 and CaCl2 type.The isotopic signature of geothermal water in western desert show far more depleted delta values compared with that of Hammam Faraoun and Ayun Musa which reflect a palaeowater of meteoric origin.

Two main mechanisms are thought to explain the source of geothermal activities in the geothermal resources of Western Desert and Sinai. The first mechanism explains the geothermal activity in the water of Ayun Musa as well as Hammam Faraoun as related to shear motion taking place along a plate boundary passing along the Gulf of Suez.The second mechanism explains the geothermal activity in the groundwater of Nubian aquifer as due to long residence time and the consequent sluggish nature , which in turn, has lead to the accumulation of heat.

INTRODUCTION

Hot springs and geysers are originally meteoric water that is heated up where sources of heat is provided by cooling magmatic masses which are quite near the surface while in areas with no magmatic activity heat is connected with particular structural conditions which determine an anomalous heat flow such as the heat generated due to the spreading of the Red Sea (Said, 1990). Early activities were carried out by Al-Ramly (1966) where according to him, in Egypt there are about 85 existing geothermal springs and wells.

However, and according to Waring's definition (1976) of hot spring as one being 8.3 $^{\circ}$C above mean air temperature (which is 22 $^{\circ}$C in Cairo and 26 $^{\circ}$C in desert) a spring or piezometer with water temperature of more than 34 $^{\circ}$C will be considered as geothermal water and many of the thermal springs and piezometers reported by El Ramly (1969) cannot be strictly classified as thermal. More recent studies were carried out in western desert by Swanberg et al.(1979,1980 and 1983).

Today hot water in Egypt is principally exploited for remediation (e.g. Ain Helwan ,Ain Al-Sukhna and Hammam Pharaoun). These forms of exploitation have been known since ancient Egyptian and have been developed especially in the above-mentioned locations. Hot water for agricultural purposes (such as geothermal greenhouse) or for industrial purposes (such as industrial heating and refrigeration) (Mary et al.,1988) have not been implemented in Egypt yet. Furthermore, the transformation of thermal energy into electric energy has not been even attempted though it is economic in very remote area. The situation in Egypt as well as other developing countries, the development and exploitation of hot springs is not as rosy as would appear in industrial countries where, 1950 MW are installed in all developing countries, of which 82% is in two countries only: Philippines and Mexico (Belaineh, 1986). Indonesia and El Salvador account for a further 12% and only 6% are installed in other countries (where Egypt is not included). Location map and hydrochemical characteristics of the studied springs and wells is shown as figure 1.

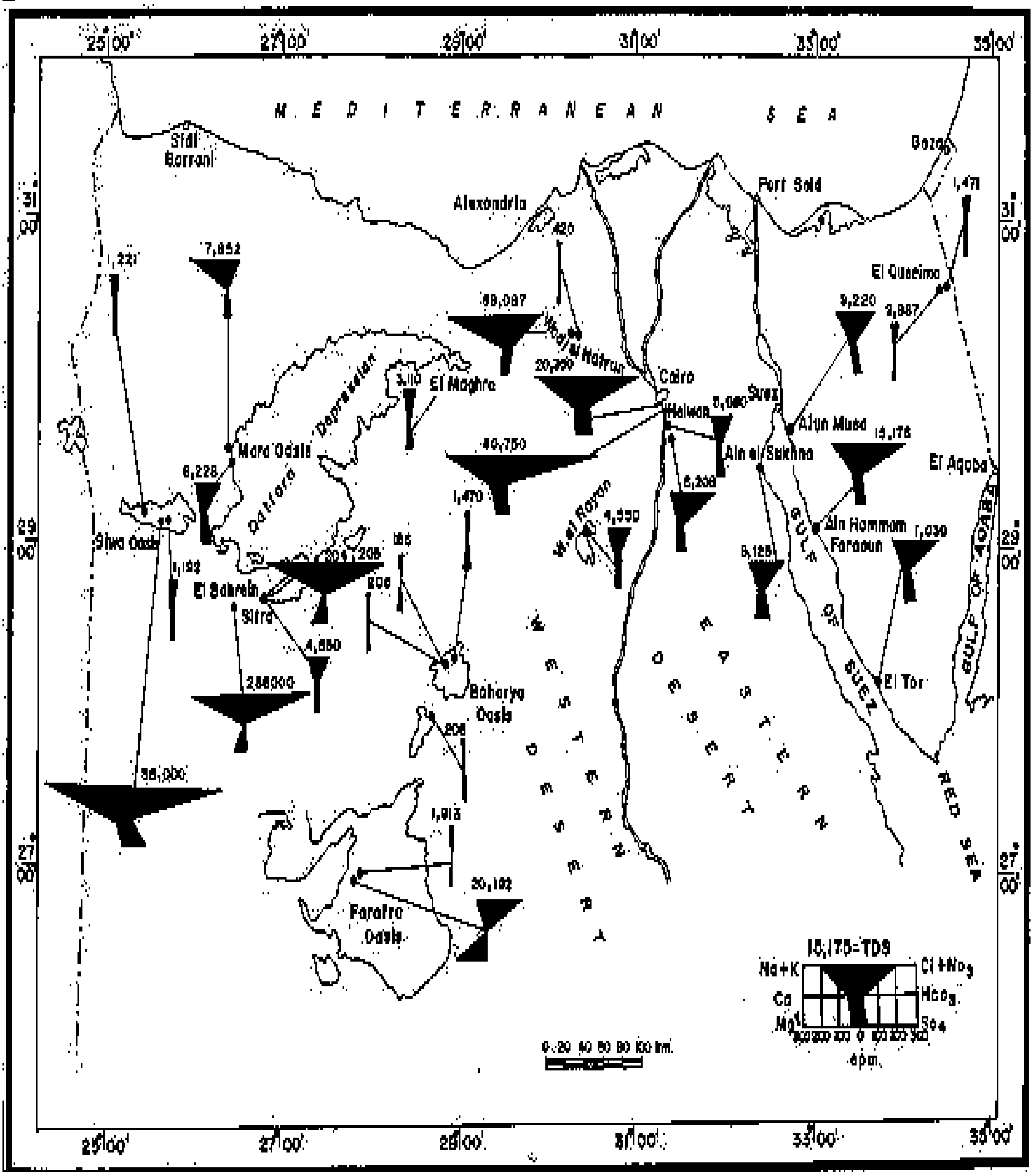

Figure 1: Old sampling sites and hydrochemical characteristics (El-Ramly,1968)

Research Methodology

Research methodologies have included the review of all isotopic and hydrochemical analyses carried out for the selected geothermal resources at the present study.

Isotopic technique

The water supply in hot springs is mainly meteoric waters which reach the reservoir from more or less distant recharge areas. The meteoric origin of the water is deduced from the isotopic composition of the waters expressed as δO-18 and δH-2. The isotopic signature was used to study the paleoclimatic condition of that water.

Hydrogeological setting

In Western Desert the geothermal resources are restricted to the five oases of Dahkla, Kharga, Farafra, Siwa and Baharia. The geology and hydrogeology of these oases has been the subject of many investigations since the pioneering work of Zittel(1883) and the early memoirs of Beadnell of the Geological Survey of Egypt (1900-1905).Outstanding amongst the publications of this period are Barthel &Boettcher (1978) ,Klitzsch et al.(1979),Barthel & Hermann-Degen (1981), Beottcher (1982), Dominik(1985), Klitzsch & Wysick (1987) and the New Geologic Map Series (EGPC-Conco1987-1988). According to Said (1990), two sedimentary basins exist on the northward-sloping African craton.These are the Dakhla basin on the west and the assiut-Upper Nile basin on the east, with the kharga upleft in between..Fig. 2 presents the geologic cross section of Nubia Basin in Western Desert. The Nubian or Nubia Basin in Egypt is underlain by fractured basement rocks and is overlain, essentially in the area north of Lat., 25^{o} N, by a thick blanket of clay and carbonate rocks (Shata,1982) and Said (1990). The sandstone succession shows conspicuous lateral change of facies and is interbedded with clay horizon, in addition to local thin carbonates. Such horizons show also lateral change of facies, which are best manifested by Fig. 2

The general behavior of the geothermal water in Nubian Basin can best be explained according to Saad et al.(1984) with two concepts complementing rather than contradicting, the present groundwater reserves of the aquifer are the result of both rainfall infiltration in situ, as well as groundwater recharge from elsewhere (Saad,1994). Furthermore, and according to many authors the age of geothermal water in the Nubian Basin varies between 20,000 and 40,000 years (Abu Zeid et al.,1994). The transmissivity varies between 100 and 10,000 m^2/day and the storativity from 1×10^{-5} to 1×10^{-1} (Margat et al., 1984). The initial head in the upper unit cropping out at Al-Kharga Oasis amounts to 50-m a.m.s.l. whereas that in Dakhla and Al-Farafra Oases amounts to 135 and 150 m a.m.s.l. Respectively (Saad et al., 1984).

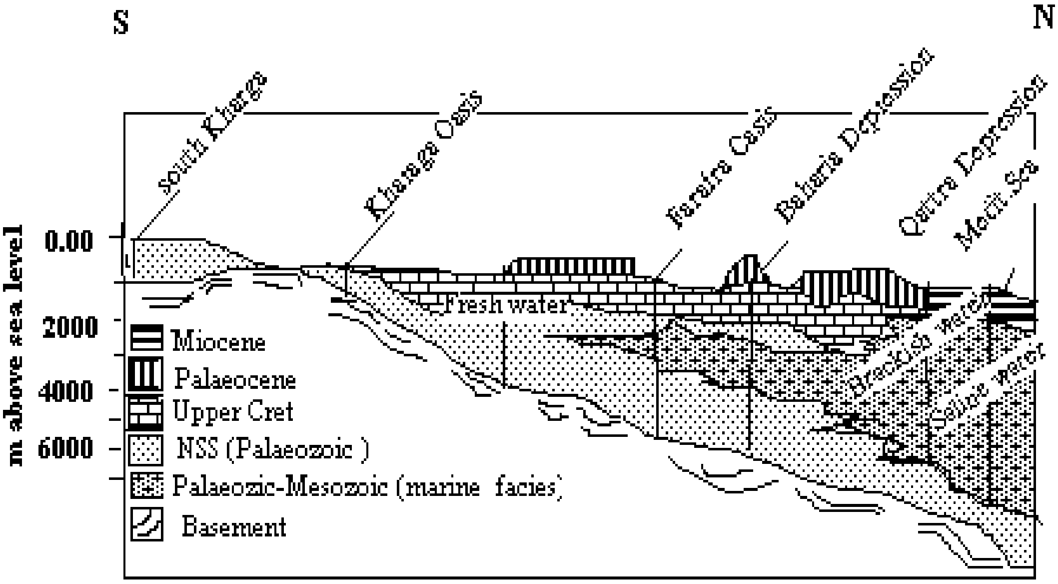

Figure 2: Nubian Sandstone Hydrogeological cross section(Egypt,1994)

This situation suggests a hydraulic connection and eventual upward movement from the underlying aquifer members to the overlying ones. The higher initial head imposed by the lower aquifer members is supported by another hydraulic evidence of discharge rates from each zone, where it amounts to 1440 m^3/d in the upper unit (of Al-Kharga Oasis)) while it ranges between 2500 and 5800 m^3/d for its lower units (of Dakhla and Al-Farafra Oases respectively).

Springs in Sinai that can exclusively be considered as geothermal are mainly clustered around the eastern side of the Gulf of Suez and are represented mainly by Ayun Musa and Hammam Faraun. According to Boulos (1990), a direct relationship appear to exist between the geothermal trends in the Gulf of Suez and the pre-Miocene relief. Lithologic logs in the Gulf of Suez show large thicknesses of Miocene evaporites in the section that may reach several thousand meters in thickness(Said, 1962). With large thicknesses of Miocene evaporites in the Gulf of Suez section, heat flow could be as high as 80 or even 100Mw/m2 (Morgan et al.1977).This may give rise to the possibility of some structural control on the geothermal gradients and the higher mean heat flow which is thought to be related to shear motion taking place along a plate boundary passing along the Gulf (Swanberg et al.1977).

Geologic data compiled from boreholes in the Gulf of Suez has shown that the section can be subdivided into two parts ; the upper part of the surface sections is made up of clastics of seeming terrestrial origin.

The lower part of the section belongs to the early Pliocene when the rising waters of Gulf came from the south .Fawzy & Abdel Aal (1984) distinguish two facies in the Gulf which they named Gihan and Morgan.The Gihan facies is made up mainly of sands with thin and minor anhydrite beds.

The Morgan facies consists primarily of of a lower unit of thin anhydrite and shale beds,, a middle salt bed and an upper unit of pisolitic limestones and sands.Ayun Musa are tapping Mesozoic sediments at a depth from 405-540 and geothermal gradient of 32 mK/m (Morgan,1985), whereas Hammam Faraoun is found to tap Eocene limestone at a depth from 5-80m with heat flow of96 Mw/m2 and geothermal gradient of47.7 Mk/m (Boulos, 1990). From the hydrogeologic point of view, Hammam Faraoun may be developed due to the contact between the Eocene limestone which show well developed karstic features and overlies far less impermeable Paleocene shale as indicated by figure 3. (Al-Gamal et al.,2002). According to Said(1990), the Pliocene epoch in the Gulf of Suez shows a section of clastic sediments of which the upper part is made up of clastics of seeming terresterial origin, whereas the lower part belongs to the early Pliocene when rising waters of the Gulf came from the south;.However, a thicker sections of more than 1000 m are encountered in some locations of marine to lagoonal origin.

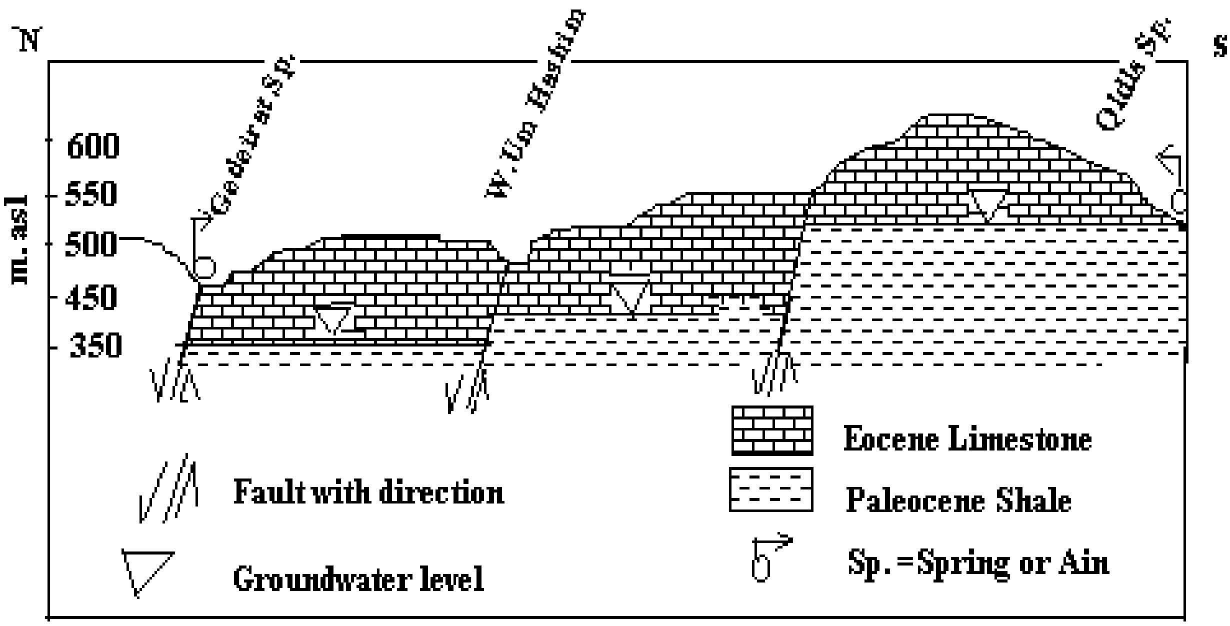

Figure 3: Hydrogeologic cross section along Northeast of Sinai (Al-Gamal et al.,2002)

RESULTS AND DISCUSSION

Geothermal characteristics of the studied springs and piezometers.

Groundwater temperature of geothermal resources for the geothermal springs and piezometers in Western Desert (Table 1) reveals that most of them are of moderate temperature ranging between 35.8 ^{o}C (Garmachin 13) and .41.9 (Table 1). The temperature of geothermal water of Al-Kharga Oasis reaches its maximum value (36 ^{o}C) at 450 m below the surface.

At only 40 m the temperature falls and has been recorded as only 32 ^{o}C.Vertical gradients of geothermal water in Al-Kharga Oasis are of the order 1.4 ^{o}C – 3.3 ^{o}C/100 m (Fig.4), whereas vertical gradients in most groundwater flow system are of the order of 0.9 –3.6 ^{o}C/100m (Domenico et al 1990).

In a more stagnant flow system where either formations are fine grained or there is little natural hydraulic gradient, the local vertical groundwater thermal gradient will be no longer owing to longer residence times (Stimson et al. 1993). Thermal stratification is observed in this system where it is related to groundwater flow regime, which in turn has an impact on the distribution of subsurface temperature.

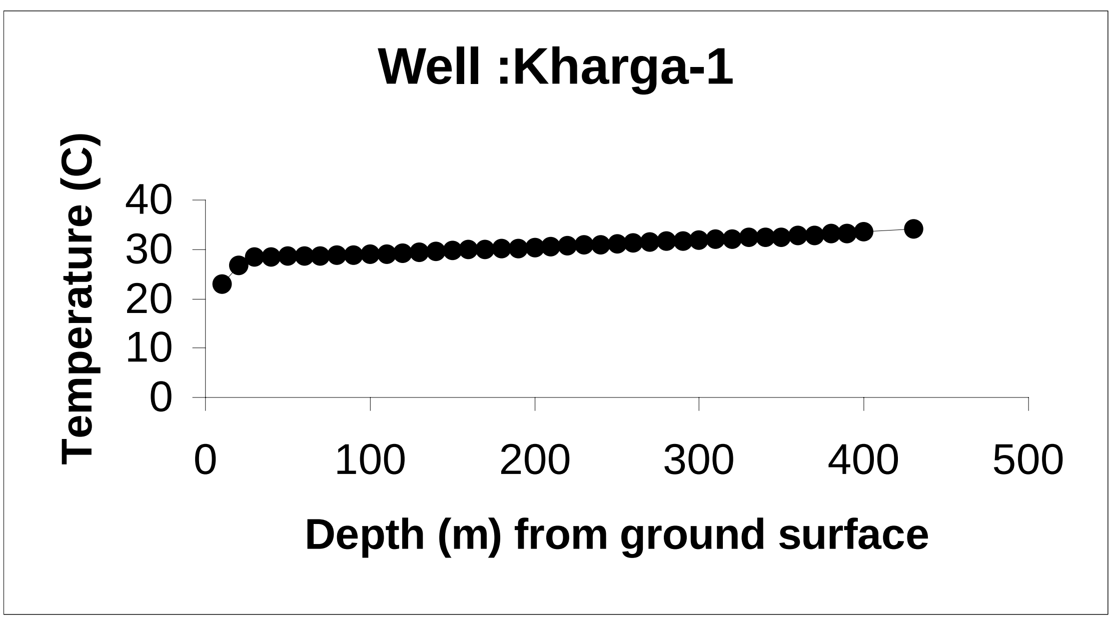

Figure 4: Geothermal gradient in the groundwater of Western Desert

In the northeastern part of Sinai, exclusively two historic locations were sampled and studied; by the present author (Al-Gamal et al.2002) these are; Ayun Musa and Hammam Faraoun both of which are located on the eastern bank of Gulf of Suez and show as high temperature as 43 ^{o}C and 75 ^{o}C respectively (Table 2). According to Morgan et al. (1983) , the mean gradient estimated for the northern Western Desert is 26.7 +-5.0` mk/m while it amounts to 26.9-+ 5.7 km/m for the Gulf of Suez and a range of 14-47 mk/m.According to him(Morgan et al., 1983) the higher mean gradient and larger standard deviation for the Gulf of Suez data indicate a different thermal regime in this area with respect to Western Desert . There is also the possibility of some structural control on the the geothermal gradients and the higher mean heat flow is thought to be related to shear motion taking place along a plate boundary passing along the Gulf of Suez (Picard 1970). This hypothesis is supported by the occurrence of hot springs on both sides of the Gulf (Swanberg et al.1977).

Hydrochemical and isotopic characteristics of geothermal resources

The major ion chemistry for geothermal water in the Western Desert as well as Sinai is shown as Figure 1 and tables 1, 2 and 3. Total dissolved solids (TDS) of the geothermal springs and piezometers in these locations range between 103-ppm (Al-Qasr 3a) and 500 ppm for Bulaq 5a. The content of H_2S ranges between 0.09 ppm to 3.5 ppm (Sadik,1996). The inspection of Table 1 reveals that the water type of these geothermal springs is of mixed water type. This water could be a mixture of water from meteoric origin having the component of KCl, NaCl, Na_2SO4, Na(HCO3), Mg(HCO3) $_2$ with water from marine origin having the components of KCl, NaCl, $MgCl_2$, MgSO4, Ca (HCO3) $_2$ (Ivanove et al., 1968).

A further inspection of Table 1 reveals that there is an increase in chloride and magnesium contents in relation to the bicarbonate which confirm mixing between two different water types. The major ion chemistry of geothermal resources in the eastern bank of the Gulf of Suez (Sinai) is shown as table 3. Electrical conductivities of Ayun Musa and Hammam Faraoun are 3.46 and 17.6 mS/cm. Ionic ratio rNa/rCl of both springs are less than unity reflecting water of mixed origin. Furtheremore, the close agreement between patterns of high Na+ and K+ concentrations and high subsurface temperature zones indicates this zone is equivalent to the discharge area of regional groundwater flow system.

Isotopic characteristics of geothermal resources

The stable isotopes of ^{18}O and ^{2}H were used for an assessment of the "genesis" (origin) of the geothermal water of the Western Desert (Table 2). Depleted $\delta^{18}O$ and $\delta^{2}H$ and low deuterium excess ($d \approx 5$-7) indicates that groundwater was recharged during cooler climate. The values of deuterium excess would have required according to Merlivat and Jouzel (1979) a relative humidity of 90% compared with 75-80% of the present arid condition of the African Deserts (Fig.5). The lower ^{3}H and ^{14}C concentration (down to 0.45 TU and 7pmc respectively) in the geothermal water of these oases suggests older groundwater that has been subjected to a dilution. This dilution could have been caused by recharge during the more humid, cool climate of the glacial epoch. Relative dating of ^{14}C data , suggests a groundwater age range of approximately from 19,000 to 34,000 years (Saad, 1984) which confirm the recharge during the glacial epoch of early Holocene and late Pleistocene. Furthermore, an abnormally high groundwater geothermal gradient in the different aquifer members exists, suggesting slower groundwater velocities i.e. sluggish nature.

The isotopic content of geothermal springs in Sinai reflects that the main source of recharge is the local precipitation originated from the air masses coming from Mediterranean Sea. (MWL) which follows the equation:

$$\delta^{2}H = 8\delta^{18}O + 10 \qquad (1)$$

where the slope is equal to 8 and the constant is equal to 10. The thermal water of Ayun Musa spring is aligned along the Global Meteoric Water Line defined by the equation, indicating a meteoric origin, while that of Hammam Faraoun shows a positive shift in $\delta^{18}O$ content (Fig. 6). This small and positive shift is due to the fact that the system is already close to equilibrium. Geothermal exchange (leading to a slight enrichment in ^{18}O) is observed in the springs of Sinai compared with the geothermal springs of Western Desert. The origin of air masses for the Sinai springs appears to be different for that from the Western Desert (influence of the Mediterranean Sea and entry of marine air). No marked evaporation took place for the water of geothermal springs and piezometers in Western Desert during rain event as can be concluded from Fig. 5. Where, data points are clustered above and to the left side of the MWL with slope 8.

The tritium concentrations in the Ayun Musa and Hammam Faraoun were 0 and 3 T.U, which were estimated to be recent to 1.5 years old, respectively using the exponential function model. Furthermore, it is observed that these springs are located in faulted zone which in turn may support the hypothesis that the main source of thermal energy to these springs is the hydrothermal solution released along the fault planes from deep horizons in the earth crust to higher and shallower water bearing formations.

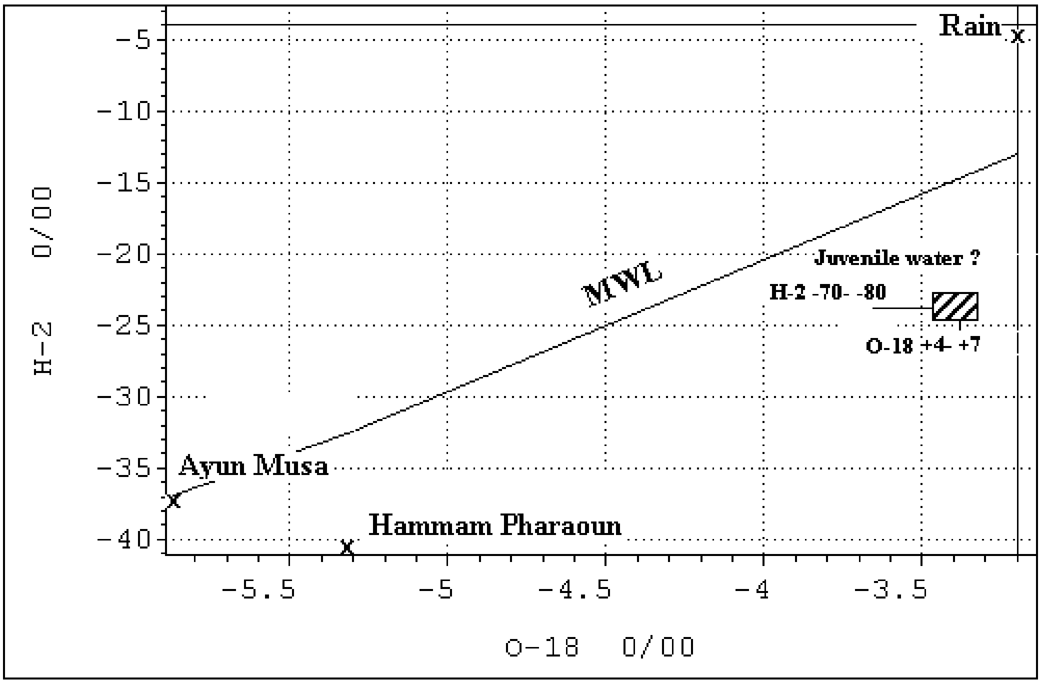

Figure 5: Cross plot of δ ^{18}O ‰ versus δ ^{2}H ‰

Table 1: Hydrochemical and isotopic characteristics of geothermal resources in Western Desert (totally after,Sadik, 1996)

Well No.	**Well Name**	**Temp. °C**	**TDS Ppm**	**Ionic ratio**				**Isotopic composition**		
				Na/Cl	Mg/Cl	Ca/Cl	Ca/Mg	^{18}O‰	^{2}H‰	d-ex.
3	Kharga 40	40.5	205	0.84	1.00	0.43	0.48	-	-	-
7	Nasser	39.9	255	0.66	0.44	0.41	0.93	-10.	-82	4.55
9	Bulak 5	35.9	261	0.68	0.43	0.34	0.77	-11	-82	8
13	Garmach.	35.8	309	0.76	0.40	0.34	0.86	-10	-81	-1
27	Tenada 8	39.9	182	0.55	0.99	0.59	0.60	-10	-81	5.5
31	Balat 40	41.9	166	1.05	0.52	0.43	0.82	-11	-82	6.22
35	Mut 3	41.8	141	0.52	0.45	0.55	1.19	-11	-83	3.46
37	Mut 23	40.1	245	1.09	0.52	0.79	1.59	-	-	-
39	Mut 25	41.7	132	0.65	0.74	0.43	0.57	-	-	-
45	Alqalamon	41.3	198	1.16	0.68	0.66	0.97	-11	-82	7.61
51	Mushia	40.3	169	0.53	0.51	0.71	1.40	-11	-81	6.95
58	Farafra 1	40.3	215	0.45	0.83	0.59	0.71	-10	-79	1.54
66	Farafra 5	40.0	151	0.76	0.66	0.97	1.46	-10	-79	0.6
71	Farafra 3C	40.2	161	0.83	0.69	0.83	1.20	-10	-81	6.00

Table 2: In-situ measurements of the two historic springs in Sinai

Sample Name	Coordinates Deg. Min. sec. Longit.	Latit.	EC (ms/cm)	(pH)	Temp °C	Depth to water, m. G.S.
Ayun Musa	32° 40′ 19″	29 48 35	3.46	8.41	43	Flowing
Hammam Faraoun	32 57 24	29 11 50	17.6	7.05	72	Flowing

Table 3: Hydrochemical and isotopic characteristics of geothermal resources in Sinai(Al-Gamal et al.,2002)

Spring Name	Hydrochemical Characteristics (ppm) Na+	K	Ca	Mg	Cl	SO_4	HCO_3	rNa/rCl	Isotopic Characteristics ^{18}O‰	^{2}H‰	^{3}H‰
Ayun Musa	255		80	30	392	125	250	0.65	-5.87	-37.27	0
Hammam Faraoun	3750	89	1060	309	7950	400	143	0.73	-5.32	-40.54	3

CONCLUSIONS

Two different mechanisms are thought to explain the source of thermal activities of the geothermal springs in Egypt. The first mechanism explains the source of thermal activities of the geothermal springs and wells in Western Desert as due to long residence time. The fact that geothermal resources in Western Desert is relatively diluted, where, ^{18}O and ^{2}H data both manifest depleted signatures and low deuterium excess, indicates that a large portion of the groundwater was recharged during a cooler and more humid, climate of the glacial epoch.

Relative dating of ^{14}C data although not conclusive, give evidence of methanogenesis occurring in the lower members of the NSS aquifer, suggests a groundwater age range of approximately from 19,000 to 34, 000 years which correspond to the glacial epoch of early Holocene and late Pleistocene. Furthermore, an abnormally high groundwater geothermal gradient in the different aquifer members exists, suggesting slower groundwater velocities.

The second mechanism explains the origin of thermal activities of the geothermal springs of Sinai as tectonic source due to the presence of these springs in the faulted zones where hydrothermal solutions are released along fault planes. A fact which is supported by the absence of any geothermal stratification in the aquifer. Recharge of modern and highly evaporated water is suggested by the ^{18}O and ^{2}H data, which manifest a relatively enriched isotopic signature.

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الينابيع الحارة فى مصركمصدر من مصادر الطاقة النظيفة

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ملخص

تشكل الينابيع الحارة واحزمة الأنشطة البركانية مصدرا مصدرا هاما من مصادرالطاقة الحرارية والكهربية النظيفة التى يمكن استغلالها وتحقيق تنمية مستدامة فى المناطق التىتتواجد بها.

والبحث الحالى يدرس اصل هذه الينابيع والية تسخين مياهها فى منطقتين مختلفتين هما الصحراء الغربية وسيناء وذلك من خلال المراجعة الشاملة للخصائص الهيدرولوجية والكيميائية وكذلك المحتوى النظائرى لبعض من هذه الينابيع الساخنة. وقد تبين لنا ان درجه حرارة مياه الينابيع الساخنة فى الصحراء الغربية تتراوح بين 35 وبين 42 درجة مئوية بينما فى حمام فرعون وعيون موسى فان الحرارة لهذه المياه تتراوح بين 45 وبين 75 وتتراوح الملوحة الكلية للمياه الساخنة بالصحراء الغربية بين 103 وبين 500 جزء لكل مليون جزء من المياه ويصل محتوى كبرتيد الهيدروجين من 009 الى 5و3 جزء فى المليون بينما تصل الملوحة الكلية لعيون موسى الى 2250 وحمام فرعون الى 11440 جزء فى المليون. ويتضح من مراجعة البصمة النظائرية لهذه العيون ان المحتوى النظائرى للمياه الساخنة بالصحر ء الغربية اكثر نضوبا فى محتواها من النظائر الأثقل (اوكسيجين-18 والديوتريوم) من نظيرتها فى عيون موسى وحمام فرعون اللتين يظهران اغناء فى المحتوى النظائرى ممايعكس تغذيتهما بمياه جوية حديثة وتعرض مياهما الى عملية البخر بخلاف المياه الحارة فى الصحراء الغربية والتى تظهر نضوبا واضحا فى المحتوى النظائرى مما يعكس ظروف شحن هذه اليانبيع بمياه جوية قديمة تمت من خلال ظروف مناخية تختلف عن الوضع المناخى الحالى. وقد انتهت الدراسة الى وجود آليتين مختلفتين لتسخين مياه هذه الينابيع. الآلية الأولى توضح ان تسخين مياه عيون موسى وحمام فرعون انما نتج عن وجودهما فى نطاق تكتونى نشط مرتبط بعملية التوسع للبحر الأحمر وهو نطاق السحق والحركة بين كلا من القشرة القارية ونظيرتها البحرية الأمر الذى ينجم عنه طاقة هائلة تؤدى الى تسخين مياه هاتين العينين .اما الآلية الثانية التىتشرح تسخين مياه الصحراء الغربية فتتمثل فى طول زمن مكوث المياه فى الخزان الرملى النوبى نتيجة لبطئ حركة المياه به وزمن شحن يتراوح من 19000 الى حوالى 30000 سنة الأمر الذى يؤدى الى تراكم للطاقة بهذا الخزان فينعكس على ارتفاع درجة حرارة مياهه.